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Title: Developing a simulation tool for evaluating in-motion detector systems.

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Developing a simulation tool for evaluating in-motion detector systems

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LA-UR-18-31233

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Motivation

In order to combat the illicit trafficking of nuclear materials, Radiation Detection Systems (RDS) are used to scan pedestrians, vehicles, cargo, luggage, and other conveyances. Many of these systems are used in an “in-motion” configuration where the detector or target are moving past the other. Current modeling and simulation tools lack the ability to produce time-series detector response profiles for in-motion applications.

Outline

- Background
- Experimental Setup
  - RS-700 Detection System
  - Profile Measurements
  - Background Variation Measurements
  - Verification Measurements
  - Gantry Measurements
- Simulation Methodology
- Results & Analysis
  - Tool Development
  - ROI Time-Series Comparisons
  - Algorithm Comparisons
  - Assumptions & Limitations
- Conclusions
- Future Work

Background

- NSDD* deploys variety of detection systems
- Time & resource intensive test campaigns
- Evaluating proprietary algorithms
- Simulation & modeling tools ease burden
- Model specific to detector system for replay and algorithm evaluation

*Funding Agency

Background

- Goal of this project to produce tool that can be used to inform test campaign measurements
- Determine best configuration to be able to detect target quantity of threat material in a specific use-case
- Quickly test many configurations to produce ROC curves and/or turn-on (s-curve)

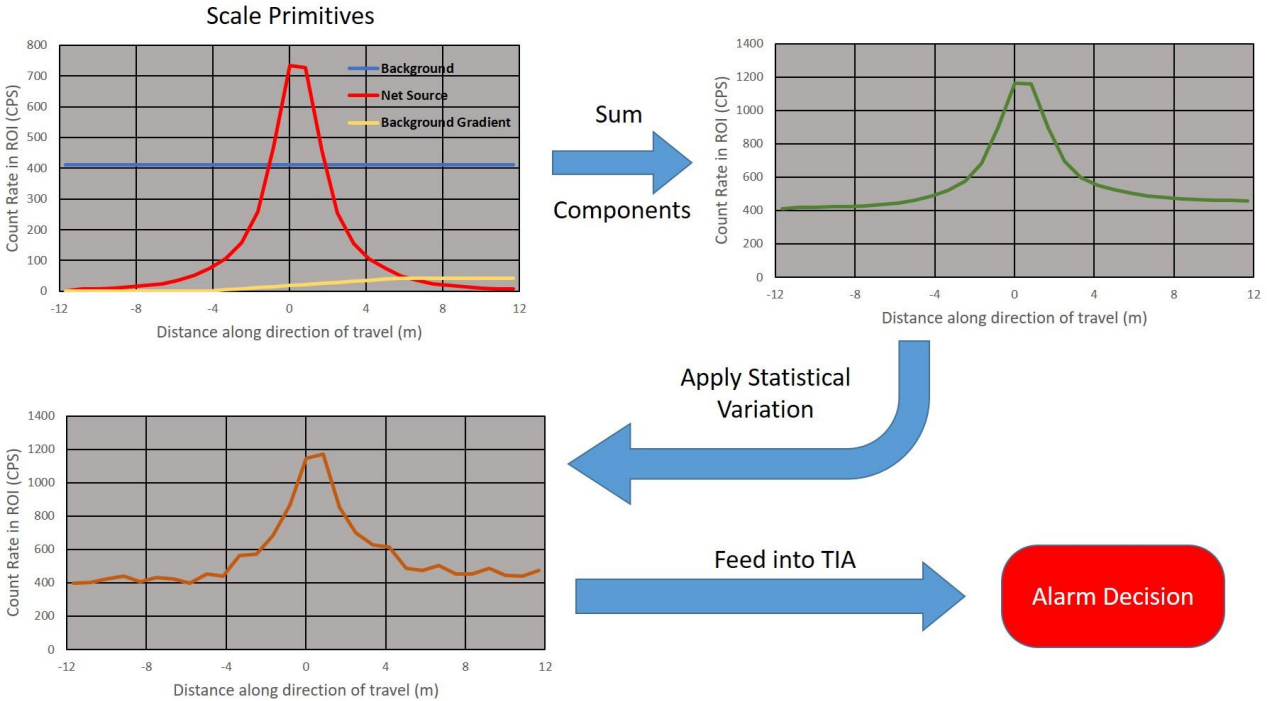
Experimental Setup – RS-700

- Radiation Solutions Inc.
- Modular & highly configurable system
- Promising results in previous work at LANL
- Several use-cases being considered by NSDD

Experimental Setup – RS-700

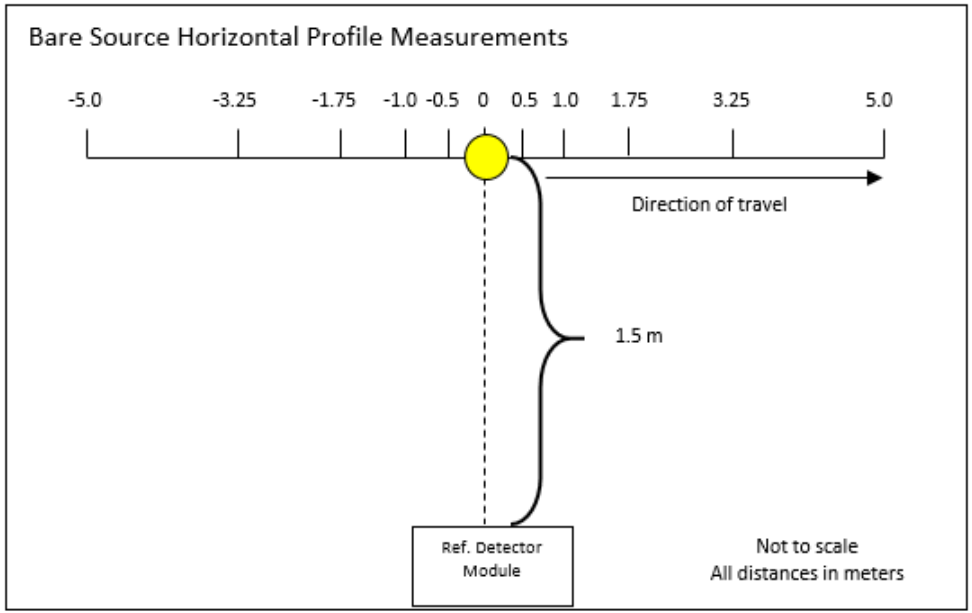
- 4-2”×4”×16” NaI crystals
- Controller + RadAssist
- External on utility trailer
- Virtual detector configuration
- 1024 channel MCA with automatic gain stabilization

Simulation Flowchart



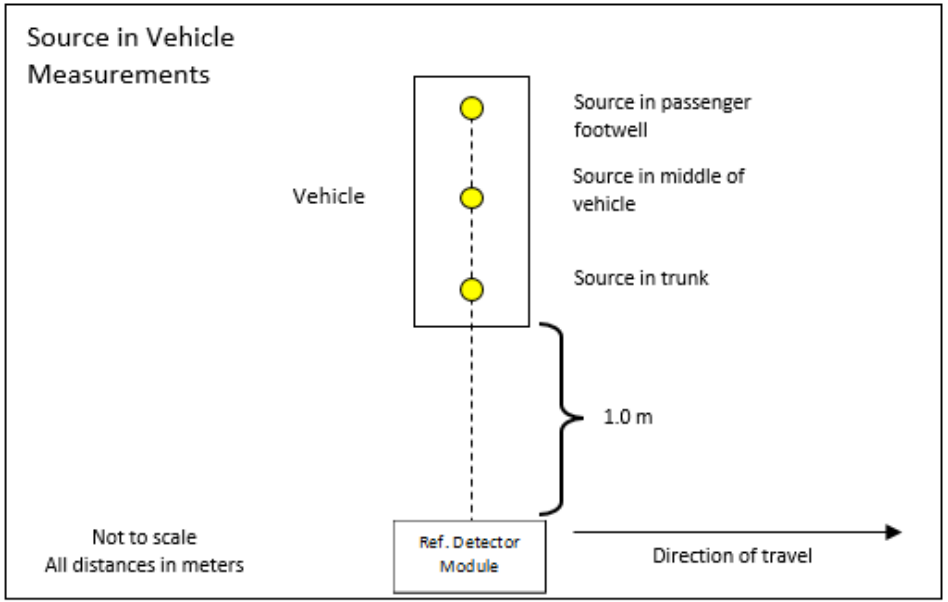
Experimental Setup – Profile Measurements

- Basis set
- Long dwell, low statistical uncertainty
- 11 measurement locations
- 6 sources used
- HEU, DU, WGPu, ^{133}Ba, ^{137}Cs, ^{57}Co



Experimental Setup – Source-in-Vehicle Measurements

- Centerline only
- Long dwell, low statistical uncertainty
- Primitive for change in spectrum due to shielding
- Distance and height of each source measured

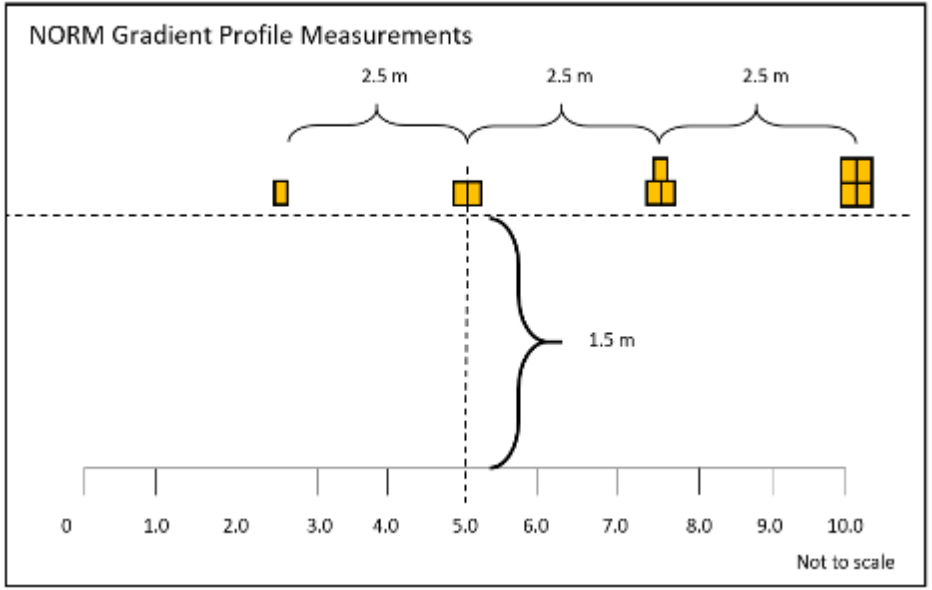


Experimental Setup – Background Variation Measurements

- Drive-about @ Coronado Mall
- ~3 hours data collected at constant speed
- Representative of urban area background variation

Experimental Setup – NORM Gradient Measurements

- Engineered NORM gradient
- Injected into simulation for detector-in-motion trials
- Background variation may challenge TIA
- Sampled from drive-about distribution



Experimental Setup – Verification Measurements

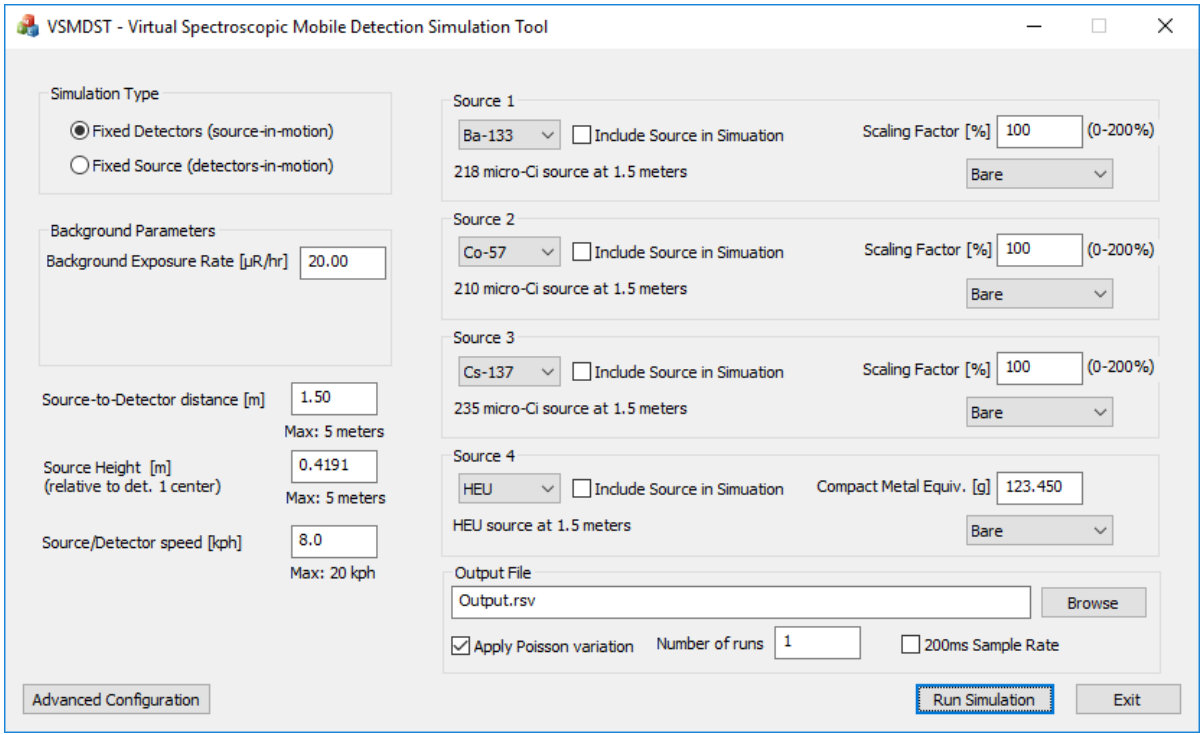
- In-motion measurements
- 17 configurations as MDS
- Used to validate output of simulation

Source	Source Location	Engine Speed	source-to-detector distance
HEU	Trunk	600 RPM	138 cm
HEU	Middle of Car	1200 RPM	309 cm
HEU	Bare	600 RPM	150 cm
HEU	$\frac{1}{4}$" Steel	600 RPM	150 cm
HEU	2" HDPE	600 RPM	150 cm
WGPu	Trunk	600 RPM	134 cm
WGPu	Foot Well	600 RPM	404 cm
WGPu	Bare	1200 RPM	150 cm
WGPu	$\frac{1}{4}$" Steel	600 RPM	150 cm
WGPu	2" HDPE	600 RPM	150 cm
DU	$\frac{1}{4}$" Steel	600 RPM	150 cm
DU	2" HDPE	600 RPM	150 cm
CS-1	Trunk	600 RPM	149 cm
CS-1	Middle of Car	600 RPM	310 cm
CS-1	Foot Well	600 RPM	399 cm
I3-598	Bare	600 RPM	150 cm
1193-15	$\frac{1}{4}$" Steel	900 RPM	150 cm

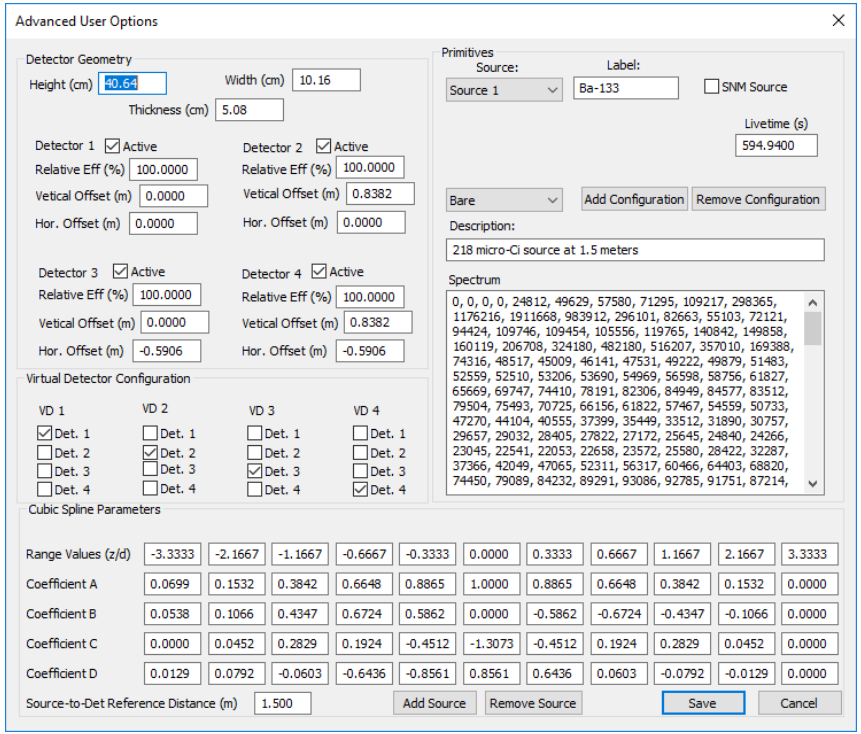
Experimental Setup – Gantry Measurements

- Used simulation tool to choose distance & shielding
- 8 configurations
- Close to limits of detection

Simulation Methodology – Basic User Inputs



Simulation Methodology – Advanced User Inputs



Simulation Methodology – Running the Simulation

- Initialize Variables
- Multi-Threading Individual Trials
- Integrate Detector Response Curve
- Create trial
- Write Output

Running the Simulation – Initialize Variables

- Configuration settings from basic and advanced UI initialized globally
- These variables do not change from one trial to another
- Faster than setting them for each individual trial

Running the Simulation – Multi-Thread Individual Trials

- Tool queries PC to determine number of logical processors
- Total number of trials evenly distributed among available processors
- Trial numbers pre-assigned to prevent overwriting

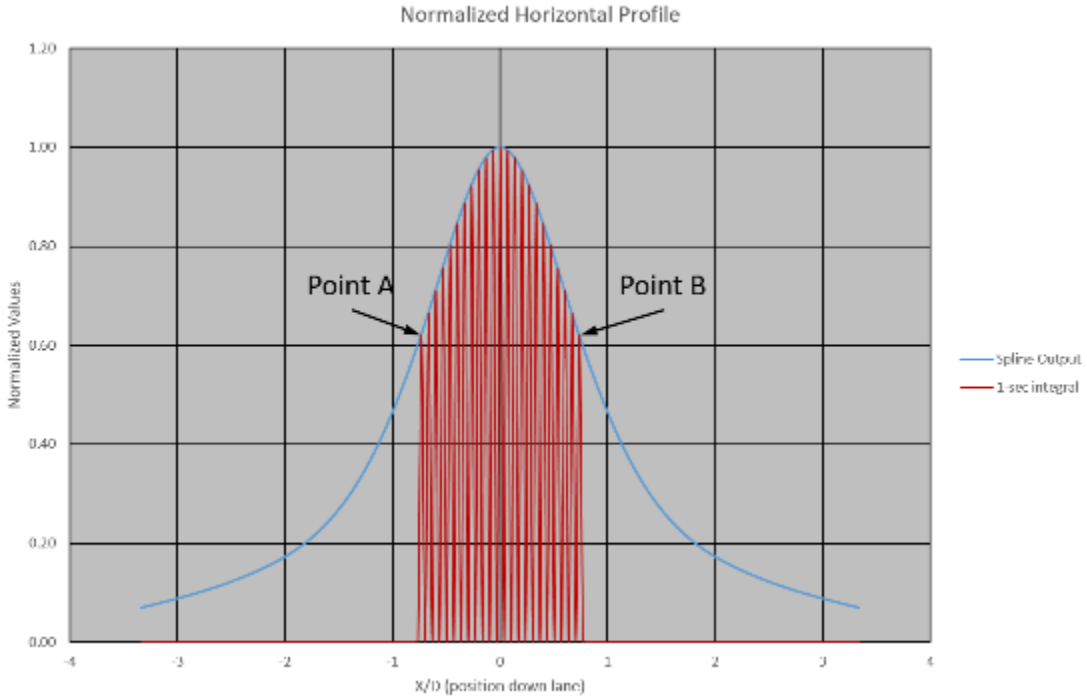
Running the Simulation – Integrate Detector Response Curve

$$\varepsilon = \frac{\int_a^b \left[A + B\left(x - X(i)\right) + C\left(x - X(i)\right)^2 + D\left(x - X(i)\right)^3\right]\left(\frac{\Omega}{\Omega_0}\right) dx}{b - a}$$

$$\Omega = arctan\left[\frac{(x_2 - x_p)(y_2 - y_p)}{z_p\left[(x_2 - x_p)^2 + (y_2 - y_p)^2 + z_p^2\right]^{\frac{1}{2}}}\right] - arctan\left[\frac{(x_1 - x_p)(y_2 - y_p)}{z_p\left[(x_1 - x_p)^2 + (y_2 - y_p)^2 + z_p^2\right]^{\frac{1}{2}}}\right]$$

$$- arctan\left[\frac{(x_2 - x_p)(y_1 - y_p)}{z_p\left[(x_2 - x_p)^2 + (y_1 - y_p)^2 + z_p^2\right]^{\frac{1}{2}}}\right] + arctan\left[\frac{(x_1 - x_p)(y_1 - y_p)}{z_p\left[(x_1 - x_p)^2 + (y_1 - y_p)^2 + z_p^2\right]^{\frac{1}{2}}}\right]$$

Running the Simulation – Integrate Detector Response Curve



Running the Simulation – Create Trial

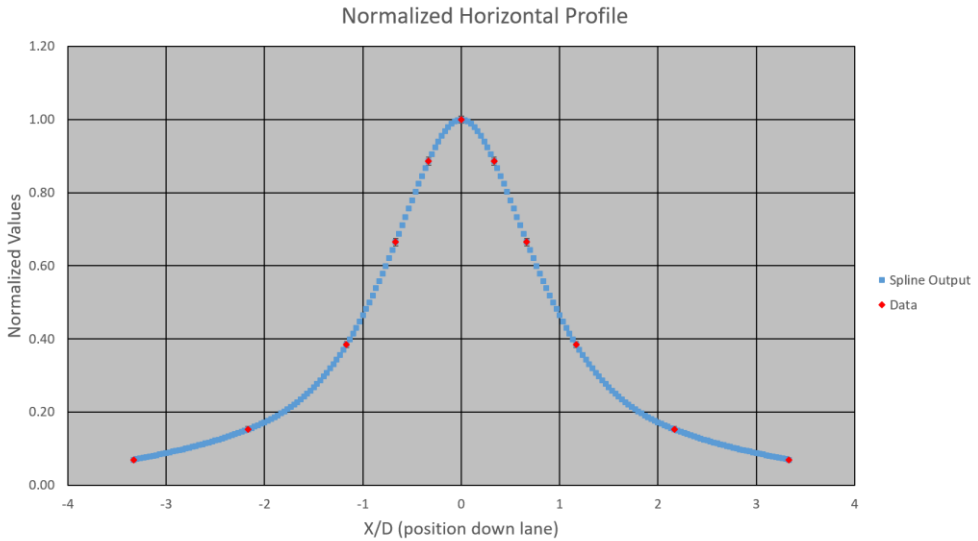
- 15 seconds background added to front and back of trial
- Individual source primitives are combined to a single one
- Multiplied by ε at each timestep from integrated detector response
- Background gradient applied from -5 to +5 meters

Running the Simulation – Write Output

- .n42 & .rsv files are created
- .n42 is ANSI standard format, time-series spectra for each virtual detector
- .rsv is RSI “survey” file, which contains same information as .n42, but can be loaded into RadAssist replay tool

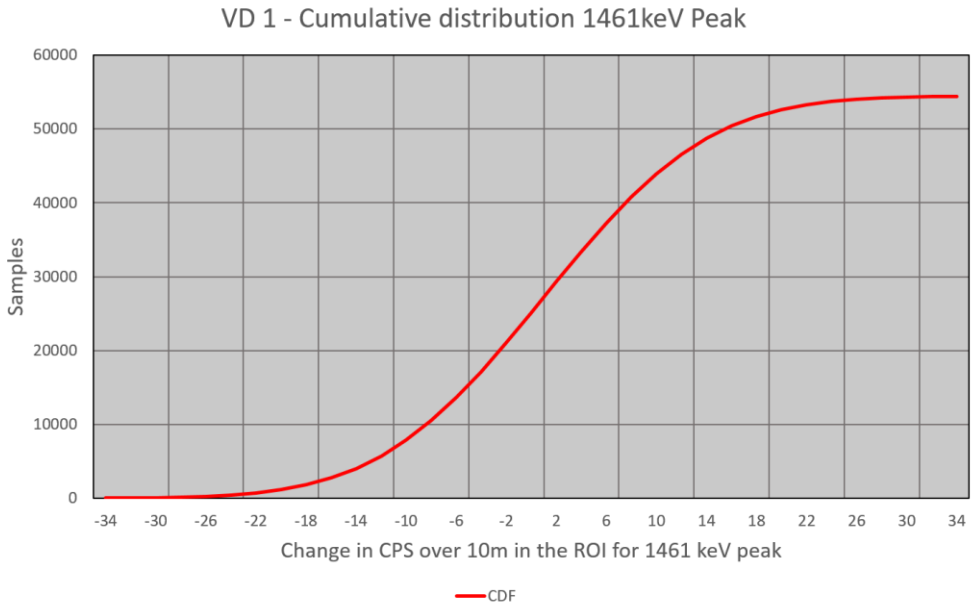
Results & Analysis – Detector Response Profile

- 6 source average
- Specific ROI for each source
- Normalized to center measurement



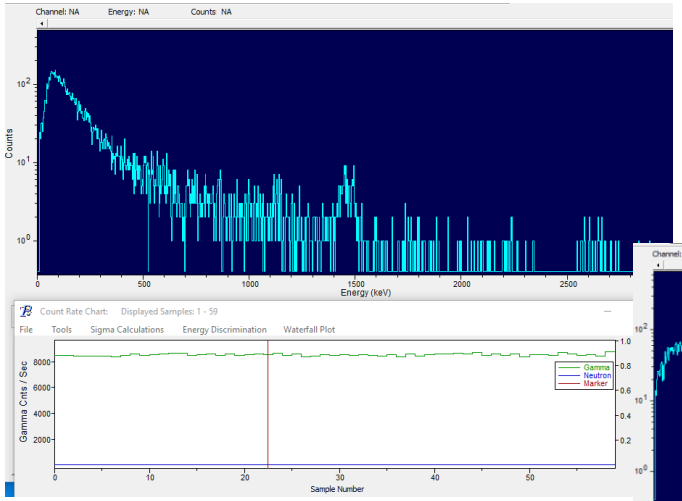
Results & Analysis – Background Variation

- ~54,000 data points
- $\bar{X} = 0.0 \frac{cps}{10m}$
- $\sigma = 10.4 \frac{cps}{10m}$
- Detector-in-motion simulations sample randomly or select percentile

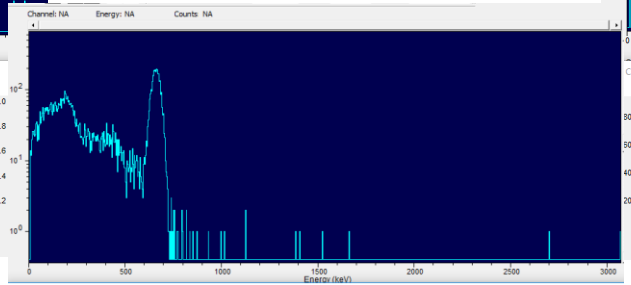


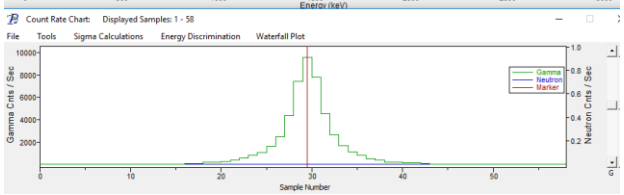
Results & Analysis – Simulation Components

Background

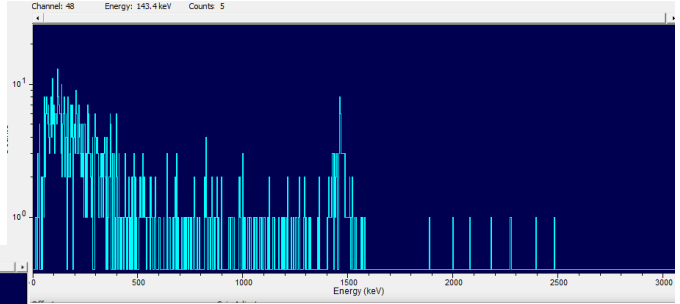


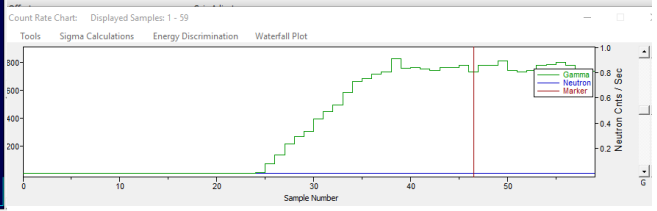
Source





Background Gradient

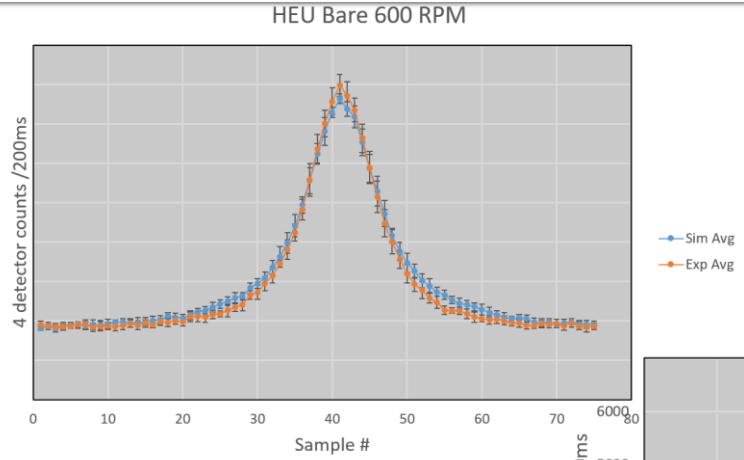


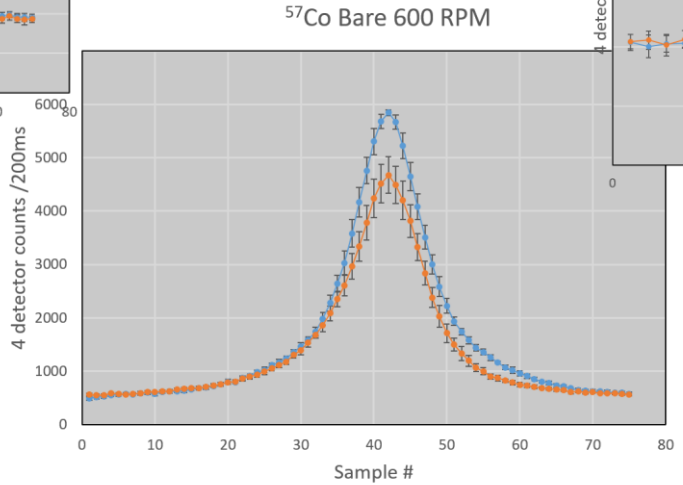


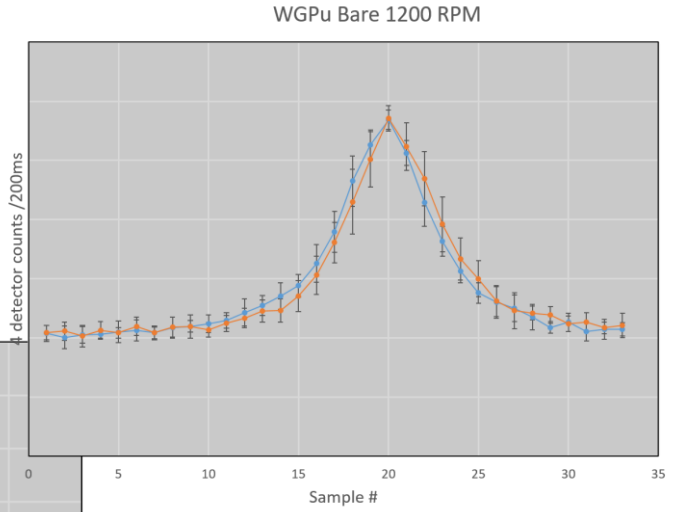
Results & Analysis – In-Motion Comparisons

- MDS setup – 17 configurations
- Gantry setup – 8 configurations
- Limited SNM & DU results presented
- Spectral ROI comparisons
- RSI TIA comparisons

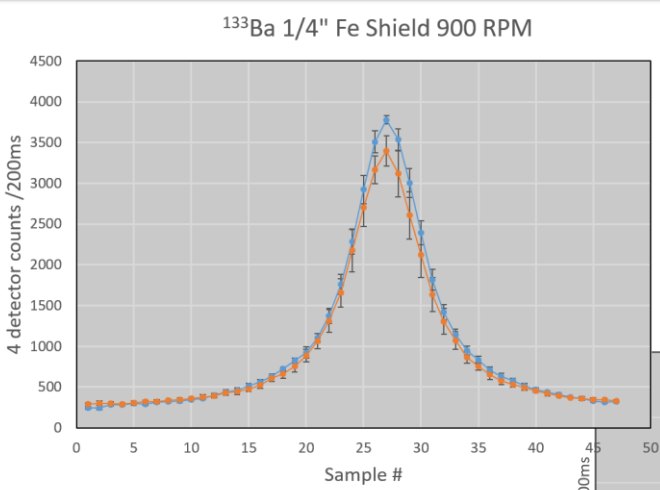
Results & Analysis – Bare Sources

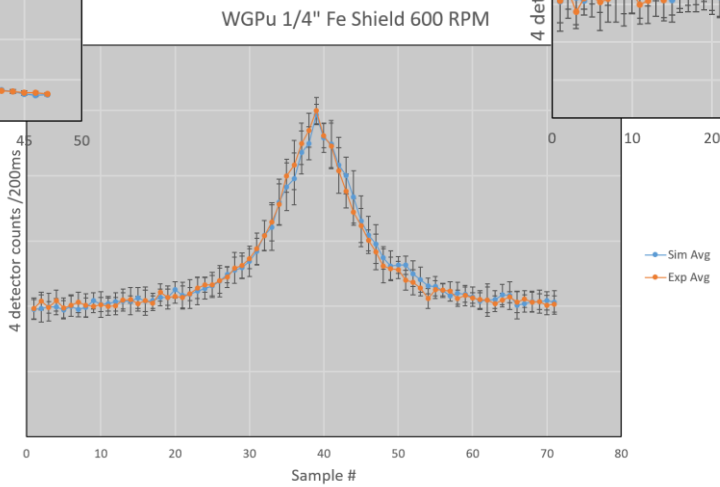


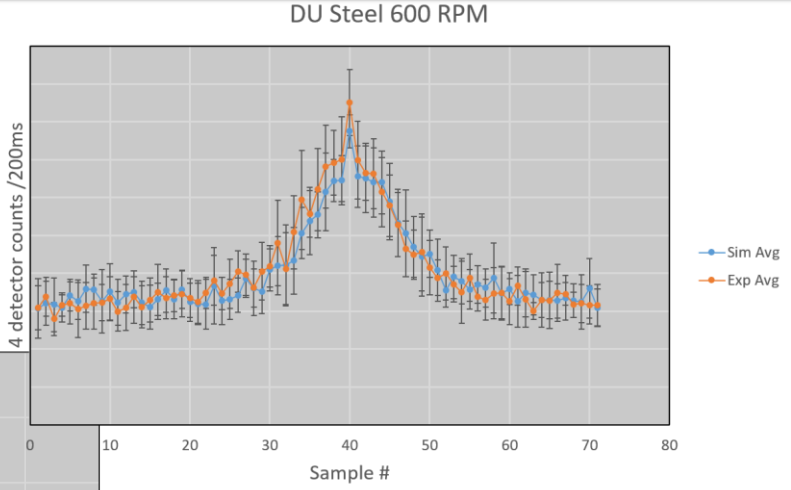




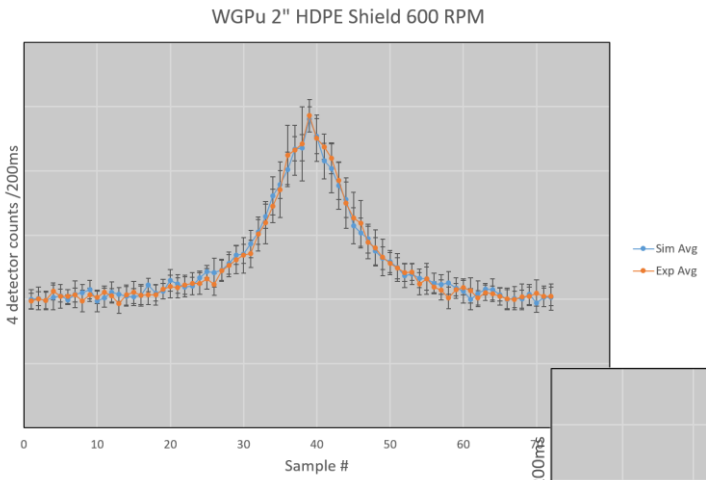
Results & Analysis – Steel Shielded Sources

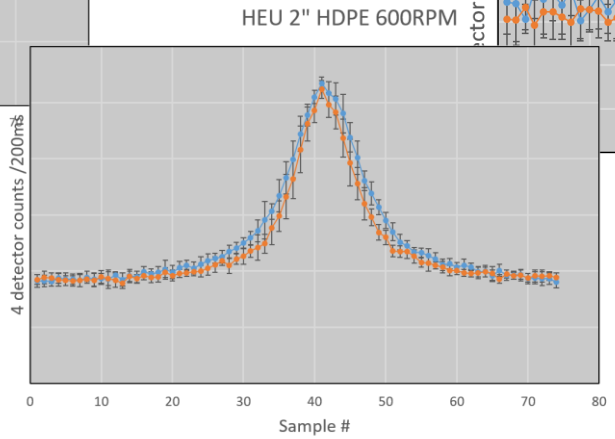


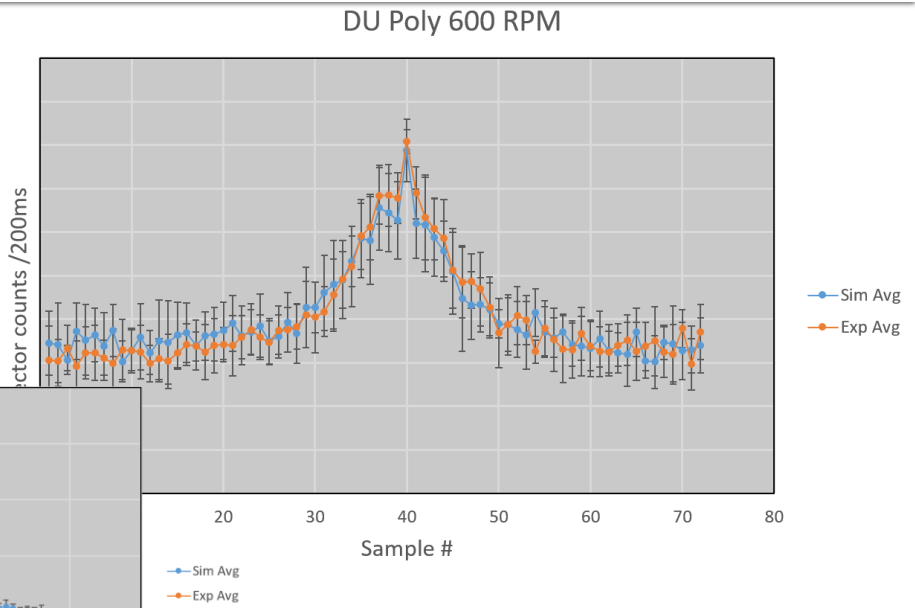




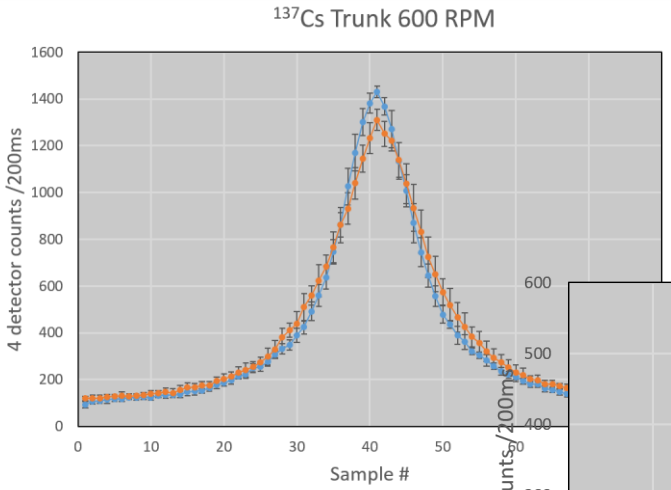
Results & Analysis – HDPE Shielded Sources

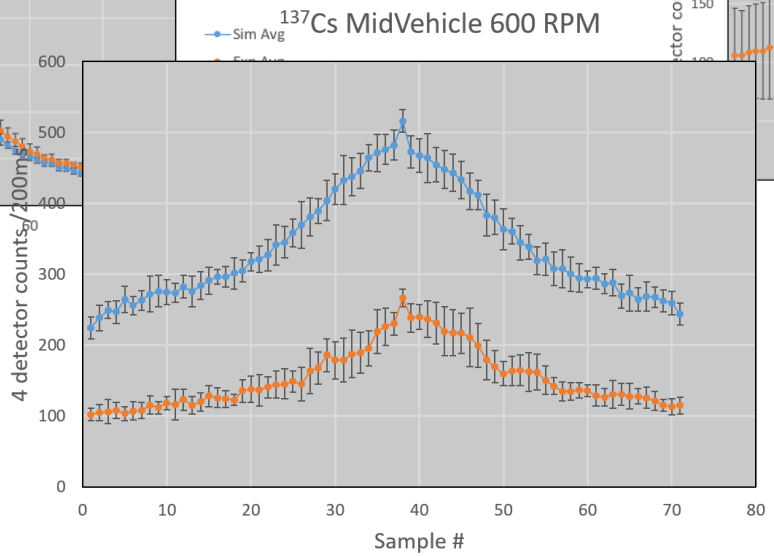


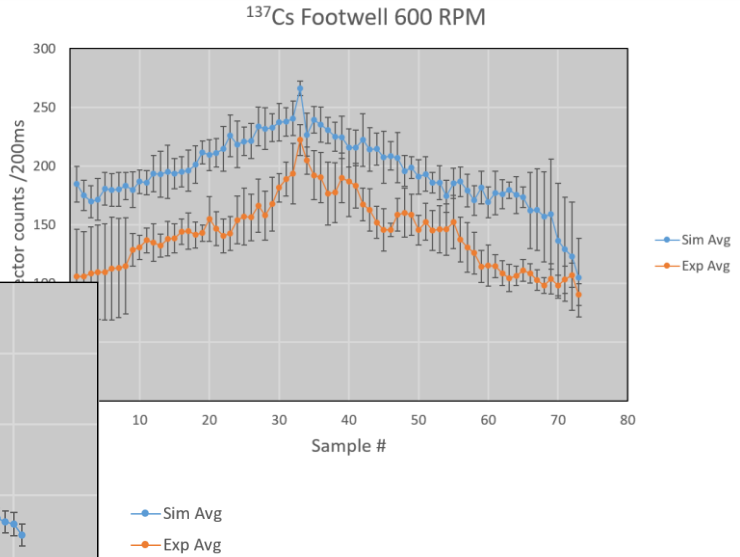




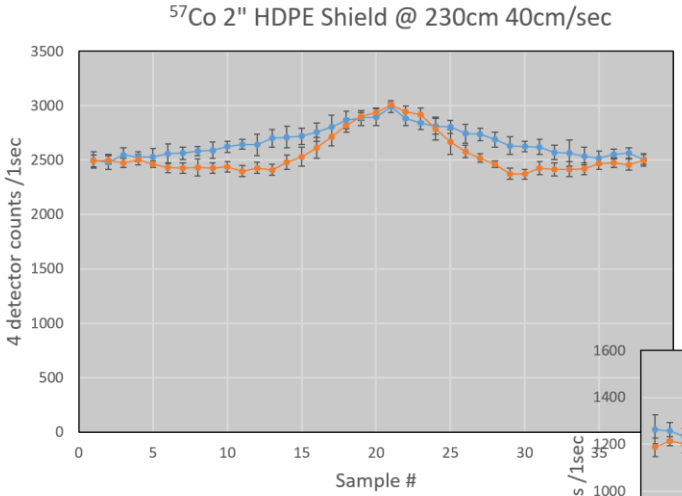
Results & Analysis – Source in Vehicle

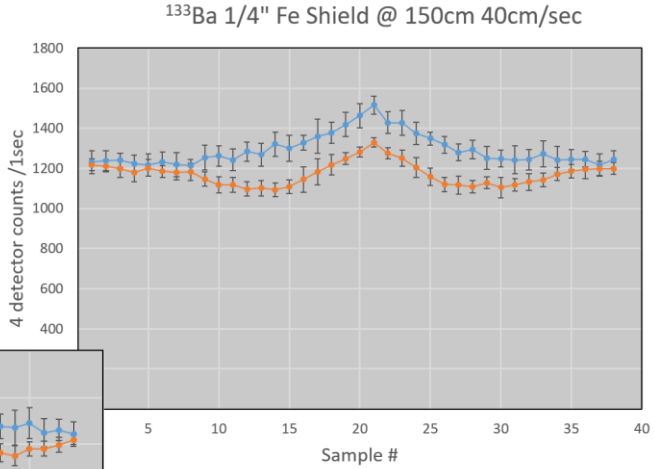


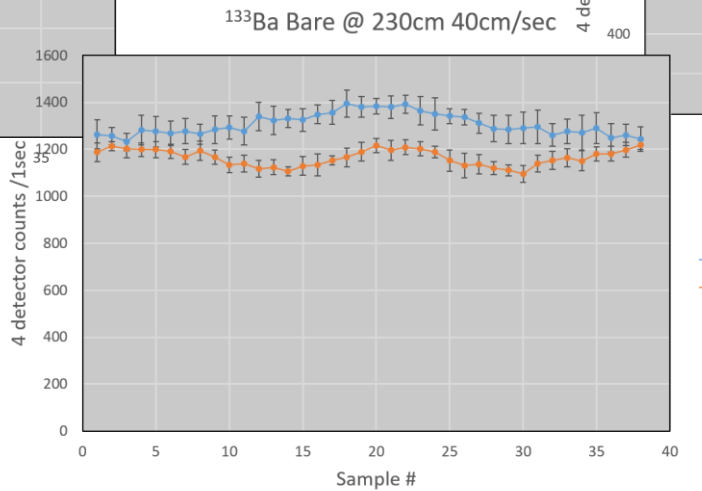




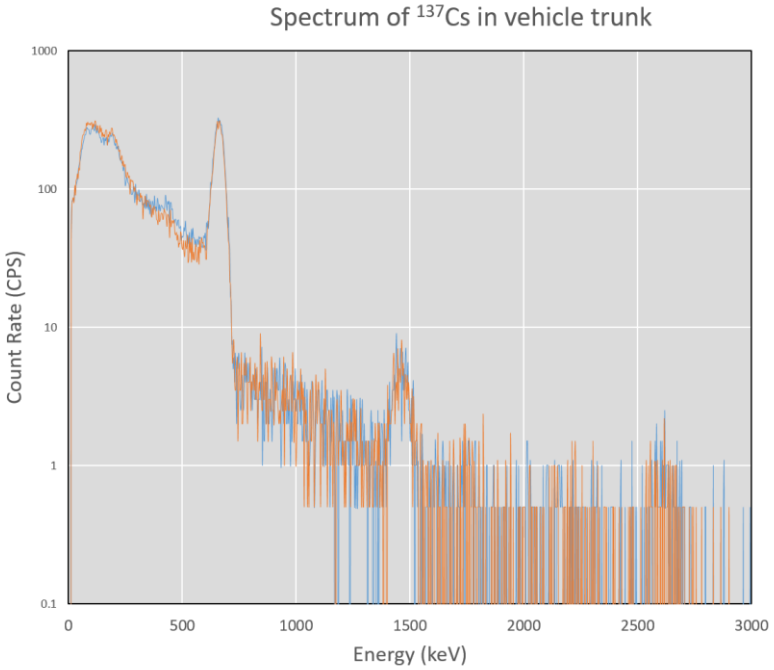
Results & Analysis - Gantry

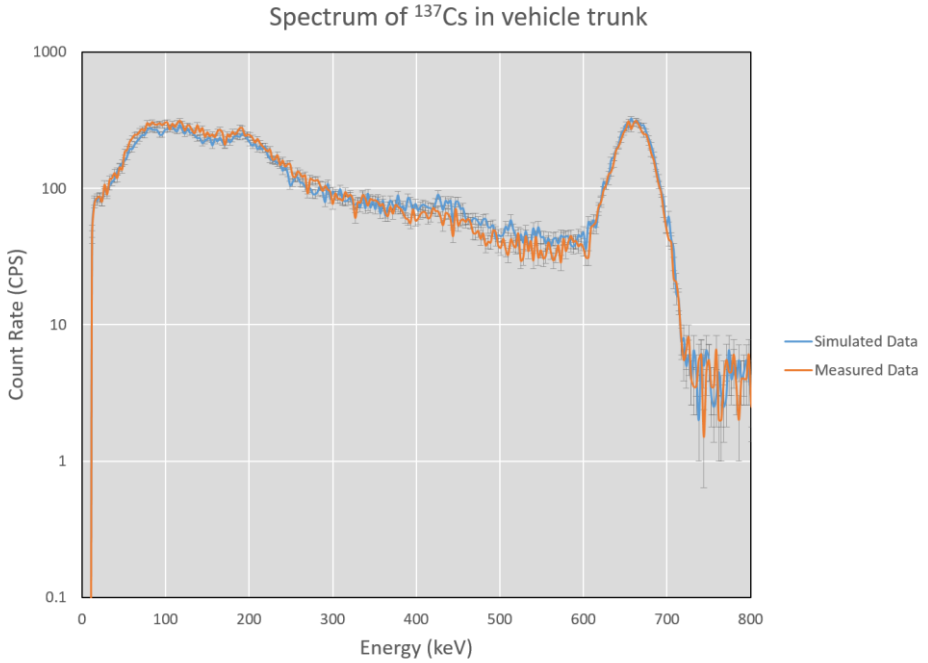




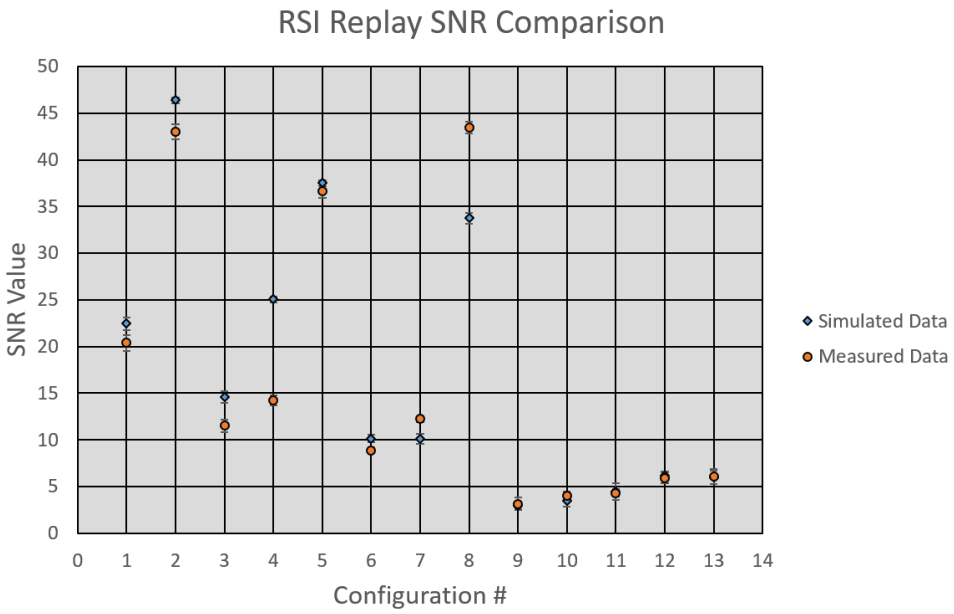


Results & Analysis – Spectrum Comparison



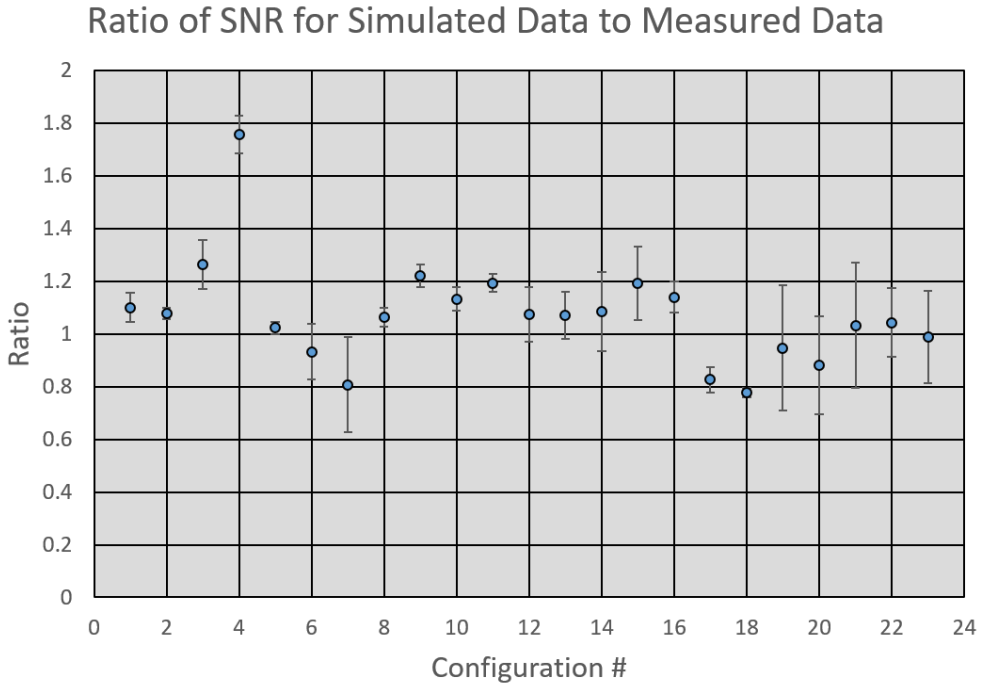


Results & Analysis – TIA SNR Comparison



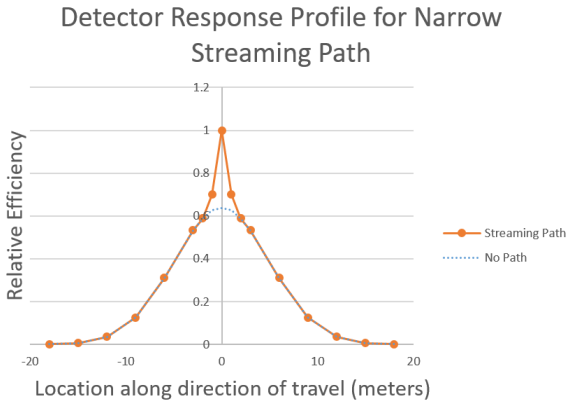
#	Configuration	Simulated Correct ID	Simulated SNR	Measured Correct ID	Measured SNR
1	^{133}Ba Fe 900RPM	10	22.5 ± 0.7	10	20.4 ± 0.9
2	^{57}Co Bare 600RPM	10	46.4 ± 0.3	10	43.0 ± 0.8
3	^{137}Cs Footwell 600RPM	10	14.6 ± 0.6	10	11.5 ± 0.7
4	^{137}Cs MidVehicle 600RPM	10	25.0 ± 0.3	10	14.3 ± 0.5
5	^{137}Cs Trunk 600RPM	10	37.5 ± 0.3	10	36.7 ± 0.8
6	1820-84-3 Fe 230cm	10	10.1 ± 0.4	10	8.9 ± 0.3
7	1820-84-3 HDPE 230cm	10	10.1 ± 0.5	10	12.2 ± 0.3
8	1820-84-3 Bare 40cm	10	33.8 ± 0.6	10	43.4 ± 0.6
9	FN-591 Fe 150cm	4	3.0 ± 0.4	2	3.1 ± 0.7
10	FN-591 HDPE 150cm	5	3.5 ± 0.6	3	4.0 ± 0.5
11	FN-591 Bare 230cm	5	4.5 ± 0.9	2	4.3 ± 0.4
12	IS200 Fe 230cm	10	6.2 ± 0.5	10	5.9 ± 0.6
13	IS200 HDPE 230cm	10	6.0 ± 0.7	10	6.1 ± 0.8

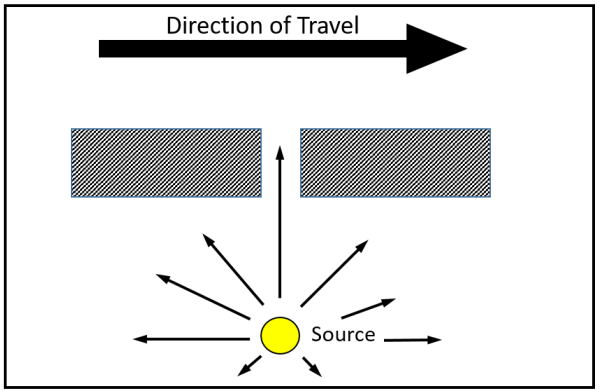
Results & Analysis – TIA SNR Comparison



Results & Analysis – Assumptions & Limitations

- Non-uniform shielding
- Streaming paths
- “Standard Vehicle”
- Pulse pile-up
- Deadtime
- 25 Sources





Conclusions

- Goal of tool to inform about what physical measurements should be included in test campaign and identify best configuration to use.
- Generally good agreement between simulated and measured data; successful in goal of the project, not an exact answer.
- 10 of 17 in-motion ROI time-series comparisons had overlapping error bars (5 of 7 outside of this were in-vehicle comparisons)
- Source-in-vehicle results not expected to be perfect with known streaming path and non-uniform shielding; could improve results by measuring profile and changing cubic spline

Conclusions

- When accounting for background suppression, 6 of 8 gantry ROI time-series comparisons were in agreement.
- Flexibility of tool to change sources, configurations, detector response, etc. reduces accuracy, but greatly increases it's value to NSDD program.

Future Work

- Sensitivity investigation to impose limits on parameters
- Incorporating background suppression
- Investigate impact of replacing solid angle calculation with energy dependent function that accounts for path length through detector media
- Additional source-in-vehicle measurements to better understand shielding that will be encountered in real-world situations
- Flexibility to be used with other systems. Backbone of tool will not change, output format and primitives on input.

Tool Demo

- Show how quick & easy it is to generate simulated trials

Acknowledgements

- Adam Hecht
- Cassiano de Oliveira, Jim Toevs
- John Rennie, Greg Orlicz
- Luc Murphy and the Office of NSDD
- Audrey Roman & Family

Questions?

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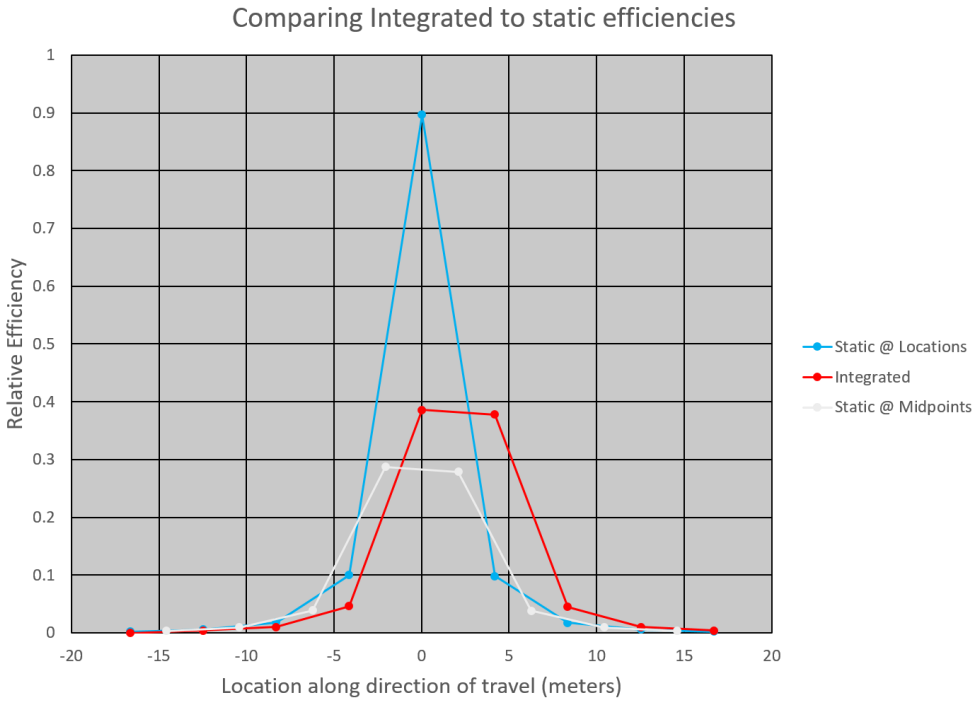
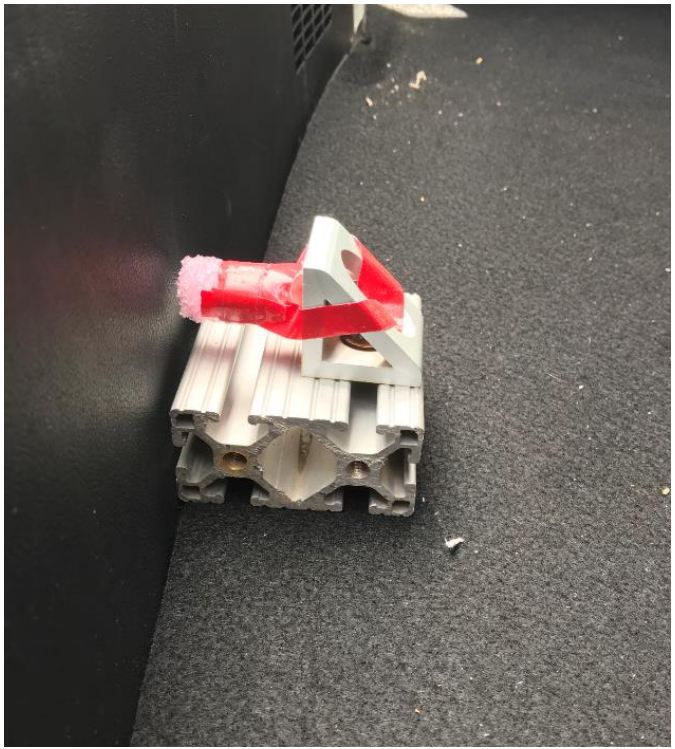
Extra Slides

Static Vs. In-Motion



^{137}Cs Source Holder Issue



SMDS Example

N42 Example

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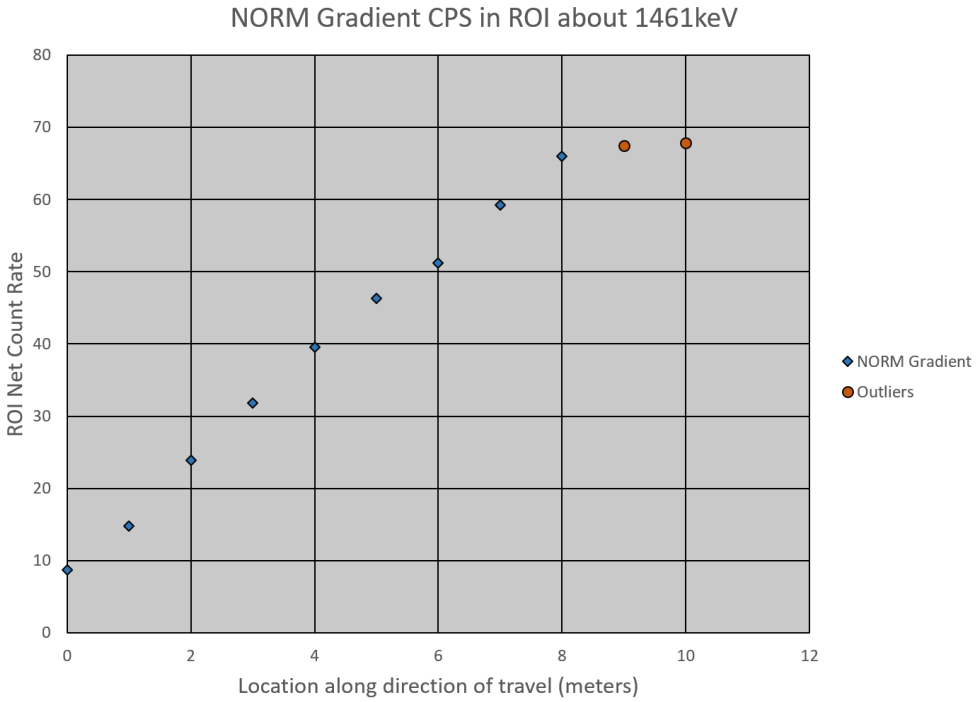

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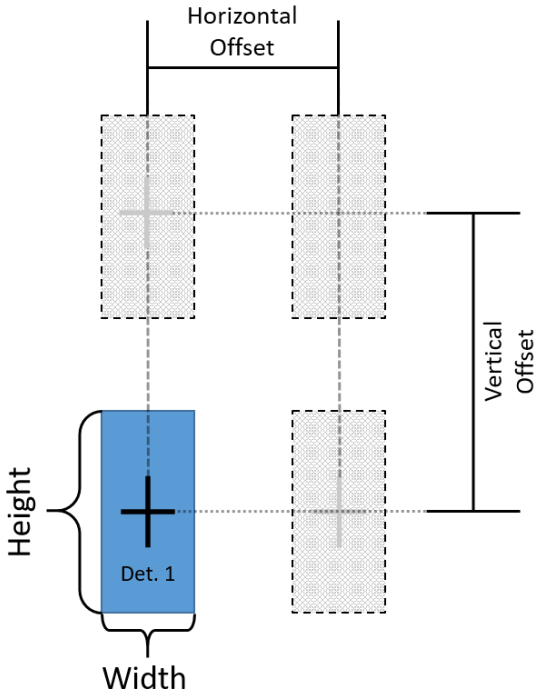
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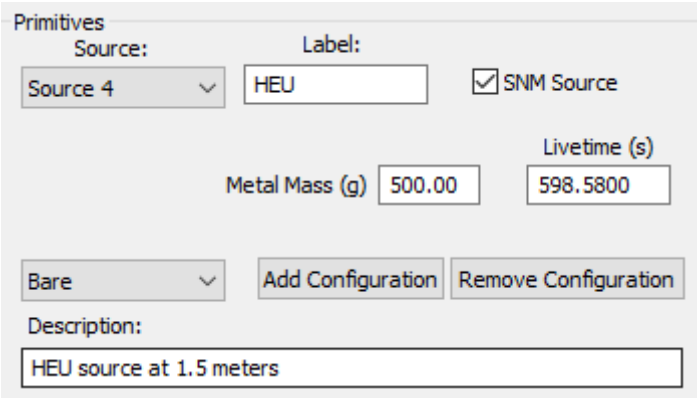
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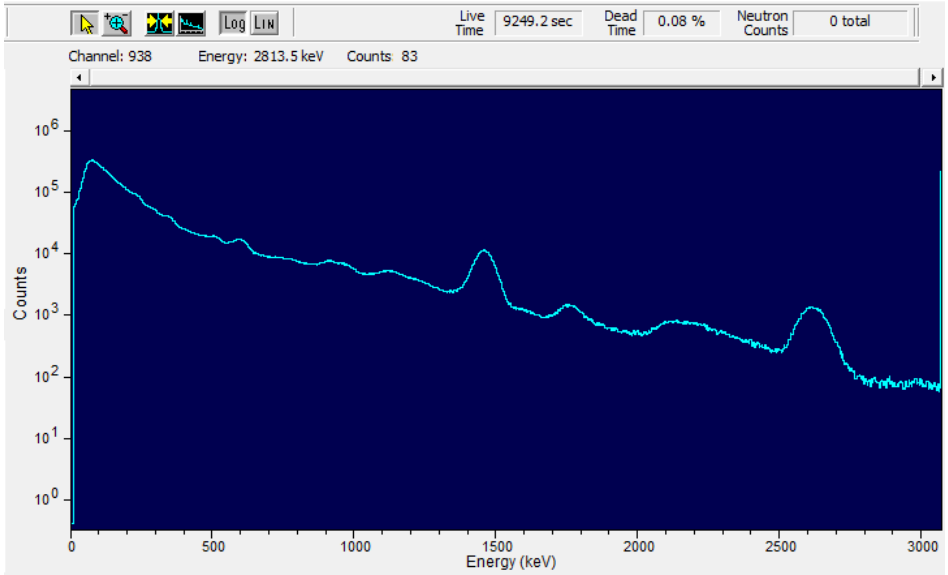
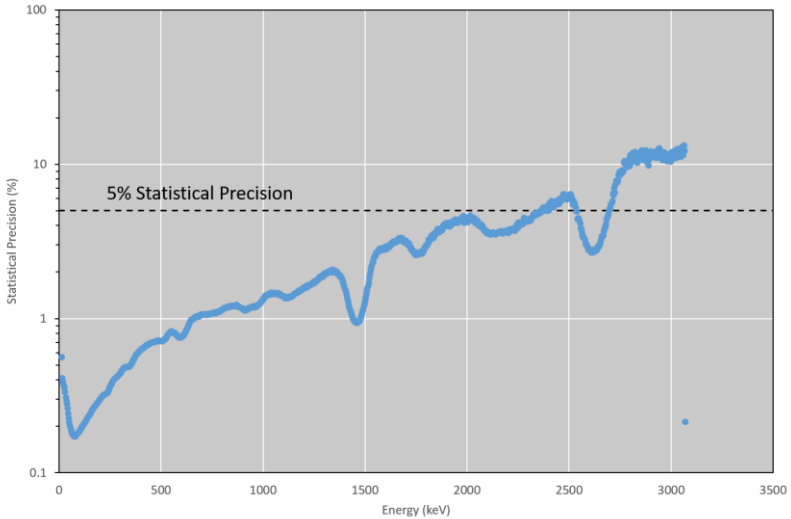
HEU source at 1.5 meters

Background Primitive





Measurement Photos

Measurement Photos

Measurement Photos

Measurement Photos